A 1 amp Current Source

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Updated 24 Apr 2013

Years ago I found a Maxim application note [maxim] that showed a simple circuit for a current source. I sent away for samples of the ICs used in the source, but then for some reason set things away in a box. A couple of months ago I came across the parts and decided to build the current source.

First, you may wonder why this current source is useful. I use it for one thing only: measuring low DC resistances. I connect the current source to the resistance to be measured, connect my DMM or system voltmeter to the resistance, then turn the current source on and read the voltage dropped across the resistance. The resistance in ohms is equal to the voltage dropped as long as the current is 1 A. Simple and foolproof. Of course, this is just the standard Kelvin-type 4-wire resistance measurement (make sure the voltmeter's leads are closer to the resistance than the current source connections). Here's the source:

The pen gives you an idea of the size (the box is 40x50x70 mm). The toggle switch is either momentary push-on in one direction or permanently on in the other direction. There's a 9 volt battery and a C battery in that box besides the electronics (it's a bit cramped in there).

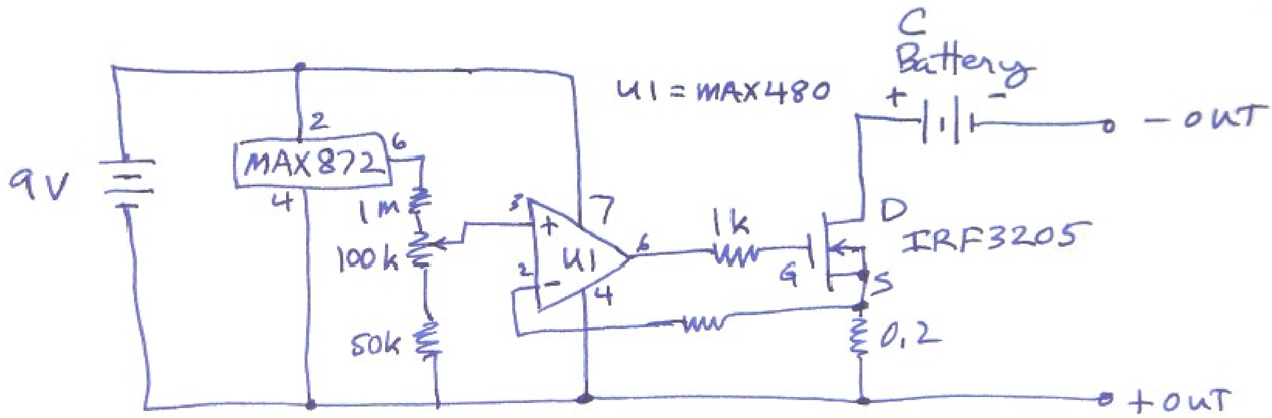
When I'm at my bench, I used to use a DC power supply to get the needed current. However, this requires using an ammeter to set the current, so it's not as convenient as these little battery-operated current sources. And, of course, the battery-operated model can be used where there's no AC power. This portable model is always handy (it sits under my computer monitor) and is always set to give 1 A of current.

When I use this current source with my Fluke 83 multimeter, I can measure resistances to the nearest 0.1 mΩ. When I use my bench multimeter, I can measure to $\mu\Omega$ levels. Once you have such a tool, you'll start measuring things like relay contacts, current shunts, and various methods of making electrical connections. Thus, for example, I found that the common strip-and-push-in connections on the back of 120 VAC outlets and switches had resistances about an order of magnitude higher DC resistance (1 mΩ vs 0.1 mΩ) than using a loop of solid gauge copper wire under a screw and tightening the screw properly. While I've always refused to use those push-in connections, now I can tell people why I don't like them. (Of course, even a 1 mΩ resistance in a 15

A 120 volt AC circuit results less than 1/4 W of dissipated power, so there's no significant heating.)

The circuit

Here's the schematic:



The power switch is in series with the 9 volt battery (I forgot to draw it). Oh, and that resistor connected to the - terminal of the op amp is also 1 kΩ.

Here's how the circuit works. The MAX872 IC is a micropower voltage reference that puts out a constant 2.5 volts. This is dropped across the three resistors. The 100 k resistor is a 10-turn trimming pot used to precisely set the voltage to the + terminal of the micropower op amp U1. This reference voltage is compared to the voltage dropped across the 0.2 ohm sense resistor and the MOSFET's channel resistance is adjusted to get the same voltage as the + input on the op amp.

The original app note specified an IRF540 MOSFET, but I switched to the IRF3205 because the channel resistance is lower, allowing me to use it without a heat sink.

I hooked the +OUT and -OUT terminals to my ammeter and adjusted the 100 k pot to get exactly 1000 mA of current. The pot's range lets me adjust the current from about 540 mA to over 1100 mA.

Unfortunately, the two ICs in the schematic are obsolete and no longer available. However, this shouldn't be too much of a hardship, as there are numerous suitable alternatives available.

The 1 A current is stable in slightly over 1 ms. Since you typically only apply the 1 A current for a two or three seconds, the batteries should last for thousands of measurements. An alkaline C battery has a capacity of about 8.35 A*hr; thus, you should get approximately 8 hours of a 1 A current from it.

About the only real construction caution I'd give is to be careful selecting the sense resistor. I originally started with some 0.1 Ω Radio Shack sand resistors I had, but they were simply not stable. I found some 0.4 Ω Daven resistors with some HP part numbers on them and two of these in parallel were beautifully stable with current through them. In other words, you need to find resistors whose voltage drop at a given current stays constant despite any Joule heating.

You can search the web to find a variety of these types of current sources for use in making low resistance measurements. I also built one using a 12 volt wall wart, an LM317, and a 1.25 ohm resistor (see the LM317 datasheet for the circuit). It works well for being so simple and cheap to construct, but you'll need to heat sink the LM317 well because it will dissipate a fair bit of power. I found it provided a stable current for 30 s, after which it needs to cool down for a bit. The current will drop 1.5% after 30 minutes, so it's not a good circuit for a continuous current. The nice thing about this Maxim design is nothing gets terribly warm (and it works for a long time from batteries).

If I were to do things over again, I would probably use David Johnson's 1 A current source design [johnson]. He used a boost converter to get a suitable voltage to operate the MOSFETs gate (and the op amp); thus, his design works using two 1.5 volt C-size batteries. He also used an inexpensive and commonly-available dual op amp IC and has an LED that lights up as long as the battery voltage is suitable.

Temperature effects

22 Jun 2011: I measured the change in current output due to a temperature drop. I put the current source box in the freezer compartment of our refrigerator for a couple of days, then measured the output with a Radio Shack 22-812 meter: 0.977 A when the temperature was around 12 °F, measured with a Cen-Tech pocket IR meter (I estimate the measurement uncertainty to be around ±5 °F, as I can get 2 or 3 °F difference by measuring different things in the freezer (I use the plastic ice bucket as the "standard", as it will have an emissivity close to 0.95). I didn't write room temperature down, so I'll assume it was 75 °F.

Assuming a linear change in output vs. temperature, this means a temperature coefficient of about 2 mA/°C or 0.2 %/°C.

Troubleshooting

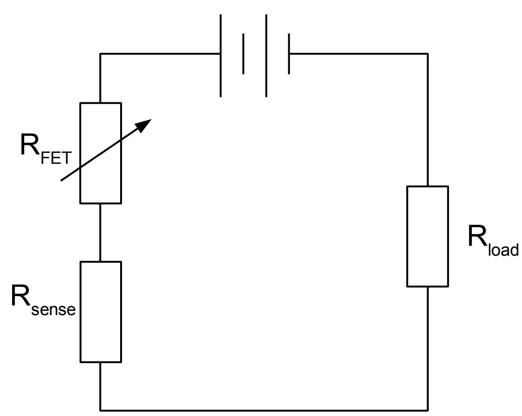
The circuit is made up of three parts: the voltage reference, the difference amplifier, and the output current loop.

If I was to make another of these current sources, I'd probably use the LM285 as a voltage reference, as I keep a stock of those. It has a temperature coefficient of 0.015 %/°C. It has a voltage output of 1.2 to 5.3 V and a low current draw on the order of 10 μA.

I would also redesign the pot that does the fine adjusting of the output current. I'd like to have a bit finer control than what I have currently.

To analyze the op amp's behavior, use the two rules from [aoe]: the output does whatever is necessary to make the two inputs equal and the inputs don't draw any current. Since the + input is the voltage reference and the - input is the voltage on the sense resistor (note both are referred to the - terminal of the 9 V battery), the op amp adjusts its output so that the voltage drop across the sense resistor matches the voltage reference. When running at 1 A output current, the op amp in my current source was putting 3.86 V onto the gate of the FET.

The output current loop is really just a battery with a resistance across it:



You can measure the voltages around the loop and they should sum to zero. Note the current source should operate just fine into a load resistance of zero (i.e., a short). If the load resistance is too high, the battery won't put out enough voltage to cause 1 A of current to flow in the loop. My current source works fine with a 1 ohm load, but I usually use it to measure resistances much smaller.

Calibration

24 Apr 2013: I've used different ammeters to calibrate this current source, but they all measure slightly different values. Thus, I'm like the man with more than one watch who doesn't know what time it is.

Since I don't have the cash to buy a good reference low resistance for measuring currents, I'll make do with what I have. My General Radio 1432-N decade resistance box has a 0.1 Ω decade. Set to 1.0 Ω, I measured its resistance using a 4 wire resistance measurement with my HP 3456A voltmeter. I set the 4 wire measurement up with the same wires/connectors as I used to set the current source's setting, so any contact resistances and thermoelectric systematic effects should be nearly the same for both measurements. With 100 power line cycles integration time, the resistance measurement stabilized at readings of 1.0198 Ω to 1.0199 Ω. The residual resistance reading when the box is set to 0 Ω is 20 mΩ. Thus the 1.0 Ω value appears to be quite close to 1 ohm.

I connected this resistor as the current source's load and used the 3456 voltmeter to measure the voltage across the resistor (there was a negligible 1.8 μV offset voltage. I adjusted the pot for the reference voltage to make the voltmeter register 1.02 volts nominal. After things were put back together, a final check showed the voltage across the resistor was 1.013749 V; the pot doesn't allow easy adjustment to closer values than this, so it's what I decided to use.

Rounding this voltage off to 1.0137, this means the actual current is 1.0137/1.0199 or 0.9939 A or 0.4% low. Since I typically only care about low resistance measurements to about 1%, this setting is adequate for my needs (and I can correct for it if I need to).

A couple of years ago I used up the last 3 of the wonderful 0.4 Ω Daven resistors I have (I used two of them for this current source) to make a current shunt. I mounted them sturdily inside a box with suitable connections. I made some careful measurements with my HP 3456A voltmeter by putting a constant current from a stable power supply[1] through this shunt resistor and the 1 ohm resistance from a GR resistance box I have. By measuring the voltage ratio across the two resistors, I found the resistance of the shunt to be 0.1330 Ω with an estimated repeatability of around 1 mΩ. I can't quantify the uncertainty because the resistance box and HP 3456A are uncalibrated (but they're close because multiple instruments I have give nearly the same measurements). When I used the current source to measure this shunt resistor's resistance, I got a rock-steady 0.13302 volts across it. That gives me confidence in both the current source's calibration and the method of measuring the ratio of the voltage drop across the resistances. Advantages of this ratio measurement are:

- It compares the two voltages within less than a second, so any drift effects are probably mostly canceled out.
- The current through the two resistances being compared are identical.
- By putting the same voltage on both input terminals, you'd better see a ratio of 1 -- this verifies the ratio measurements are making sense. The 3456 shows a ratio of 1 with an integration time of 100 power line cycles to be on the order of 5 parts out of 10^7.

A multimeter with this ratio capability is handy for comparing resistance standards. Another use is to select resistors to make a voltage divider with a desired ratio -- an advantage is that you can bias the divider with its operating voltage while measuring the ratio.

Of course, if your voltmeter doesn't have a ratio feature, just make two measurements of the voltages across the resistors and you can calculate their ratio.

References

maxim	Maxim application note #106, 9 Jul 1998.
johnson	Dave Johnson's 1 A current source, http://www.discovercircuits.com/H-Corner/1amp

1 The HP E3615A, which appears to be stable to within a few parts out of 10^6 over the ratio measurement time.

current injector.htm, Popular Electronics, Nov 1992.

aoe P. Horowitz and W. Hill, *The Art of Electronics*, 2nd. ed., Cambridge University Press, 1989.